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THE MUSE SYSTEM: DESCRIPTION AND

MANUAL FOR OPERATION

TECHNICAL REPORT NO. ESD-TR-65-94

DECEMBER 1965

A. W. Slawson

OFFICE OF SCIENTIFIC AND TECHNICAL INFORMATION

ELECTRONIC SYSTEMS DIVISION

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

L. G. Hanscom Field, Bedford, Massachusetts

Project 1700

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts
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FOREWORD

Robert Curtis, Edward Bensley, and Ferrell Sandy all contributed important ideas during the planning and programming of the MUSE Program. James Valentine and Augustine Kish designed and built the digital-to-analog converter. Professor K. N. Stevens of MIT provided very helpful criticism and the use of his sound spectrograph. Drs. F. S. Cooper and A. M. Liberman of Haskins Laboratory lent encouragement and valuable critiques. The author is much in debt to these and many other individuals.

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ABSTRACT

The MUSE system, an IBM 7090 computer program and associated conversion equipment, has been designed for use as a sound synthesizer. Concise descriptions of complex sounds including human speech are converted by the MUSE system into sound pressure waveforms. The inputs to the MUSE system are specifications of the changing resonance frequencies of multiple acoustic filter networks and of the changing frequencies and amplitudes of the sources of acoustic energy that excite those networks. The output of the MUSE system is a sampled waveform calculated for each resonance by the solution of a second-order difference equation. The results are summed over a single system of resonances and then the resonance systems are also added together. The resulting string of sampled waveform ordinates is written in digital form on magnetic tape. Conversion to a voltage waveform is accomplished by use of the standard IBM 729 IV tape transport unit and a simple digital-to-analog converter. Although the quality of the sound is somewhat degraded by tape wow and flutter, acceptable and highly intelligible speech has been synthesized.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.
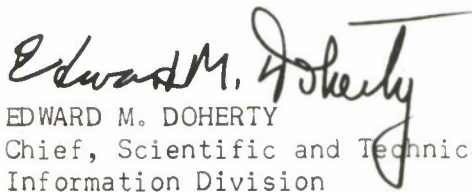
EDWARD M. DOHERTY
Chief, Scientific and Technical
Information Division

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SECTION I

INTRODUCTION

A phonetician, wishing to test his model of speech production, often describes some speech utterance in terms dictated by his model and then uses this description to control a speech synthesizer. Provided the speech synthesizer is a good one, the quality of the resulting speech is a good indication of the sufficiency of his model. The model may be too complicated or may not be limited by physiological constraints, but if high quality speech can be synthesized according to the model, it commands attention as a possible means of gaining insight into that most complicated and refined biological system — the human vocal apparatus.

The MUSE system is a computer simulation of a class of sound synthesizers that have been used with success in testing theories of speech production. In spite of some loss of fidelity, the computer simulation can be used in place of this class of sound synthesizers. MUSE, consisting of an IBM 7090 computer program and simple digital-to-analog conversion equipment, translates concise descriptions of a large class of complex sounds, including human speech, into the corresponding analog waveform. This signal can be recorded for later playback or it can be used to drive a loudspeaker for immediate presentation of the sound.

Sound synthesizers can also be used to present information in the form of spoken messages to the human operators of a computer-centered, real-time control system.[1] In such an application, these messages would be stored in computer memory in concise digital form. The main program for the control system would select some appropriate message and send it to a sound synthesizer that would then expand the concise form of the message into the corresponding wide-bandwidth speech signal and present it to the operator in real time. The MUSE system, by simulating the output of various alternative

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synthesizers, could aid in designing the simplest adequate device for each application.

The MUSE system is itself a weak theory of speech production. MUSE is a <u>weak</u> theory because it leaves unspecified the manner in which the sounds are produced and because, subject to a limited bandwidth, it can reproduce the output of a large class of acoustical devices. The limitations that make it a theory at all are mainly practical ones. MUSE couldn't be used in practice to simulate a symphony orchestra because a single chord could require thousands of statements in the input language. General statements about these limitations are impossible but they will be made explicit by the detailed description of the input language and the operation of MUSE both of which follow.

SECTION II

EQUIPMENT NECESSARY AND OVER-ALL SCHEME

EQUIPMENT NECESSARY

The equipment needed for running the MUSE program consists of a
standard IBM 7090 EDPM with at least two data channels and at least one 729 IV
tape transport unit, a special purpose digital-to-analog converter, a variable
bandpass filter, and any electro-acoustic transduction system or, preferably, a
good quality magnetic tape recorder.

OVER-ALL SCHEME

In general, the operation of the MUSE system consists of a translation
or calculation phase and a subsequent digital-to-analog conversion phase. In
the first phase, the data cards containing the sound specifications are read in
as needed and the ordinates of the specified waveform are calculated. These
numbers representing the instantaneous pressure of the specified waveform at
successive small intervals of time are stored in blocks on magnetic tapes.
When calculation is completed for the sound sample or utterance being
synthesized, the waveform ordinates are read from the magnetic tape storage
into the computer for normalization. These data are then written onto a new
tape in which the inter-record gaps between the blocks of numbers are
eliminated.

In the conversion phase the tape unit, an IBM 729 IV tape transport unit
on which the final output has been written, is disconnected from the data
channel and connected to the digital-to-analog conversion device. This device
then reads the six-bit (64 levels) waveform ordinates off the magnetic tape,
sets them in a buffer register, and converts them to a voltage waveform

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smoothed by a low-pass filter. The resulting signal can be transduced by a standard loudspeaker system or recorded on magnetic tape as shown in Figure 1.
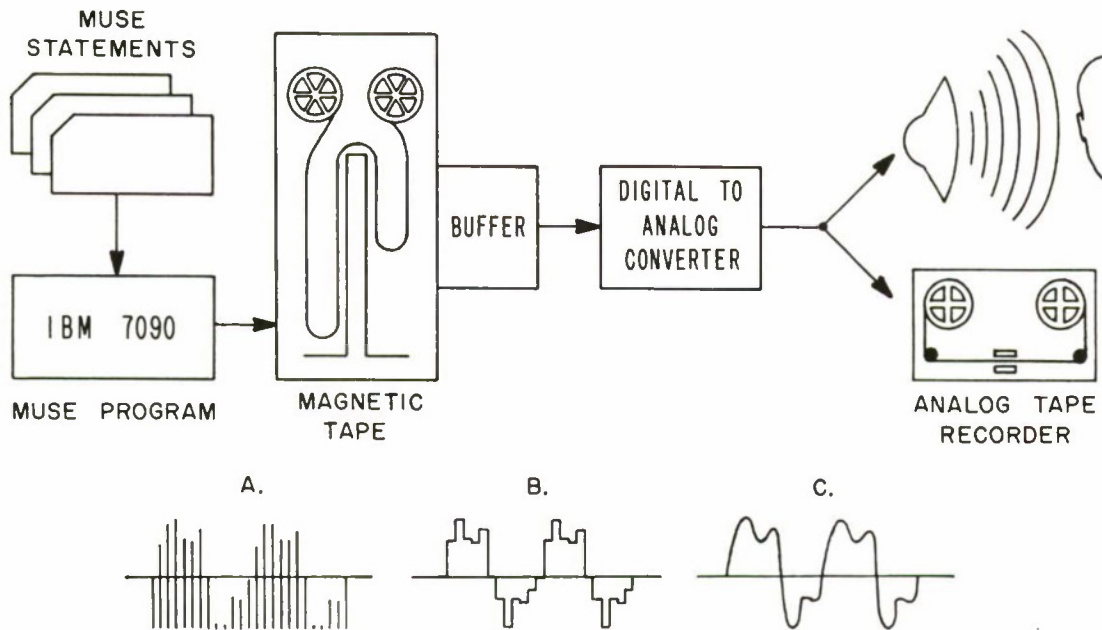
1. MUSE Statements on IBM cards are read into the computer.

2. The computed waveform ordinates (A) are written onto magnetic tape.

3. The waveform ordinates are converted into a step function (B) representing voltage levels.

4. A low-pass filter smooths the step-function into an analog waveform (C).

5. The output of the digital-to-analog converter is a varying voltage which drives a loudspeaker or tape recorder.

Figure 1. Functional Diagram of the MUSE System

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SOUND SPECIFICATION LANGUAGE AND FORMATS

INTRODUCTION

Since the common denominator of all sound synthesis systems is an output waveform, the important differences between these systems lies in the method of specifying the desired sound and in the faithfulness with which these specifications are embodied in the output waveform. The level of sophistication or, in other terms, the degree of bandwidth compression of the system is more or less fixed by the specification language. The MUSE system's specification language consists of statements describing the changing acoustic spectra of the desired sound. Representing the instantaneous frequency response of independent resonating systems at given points in time, these statements contain the resonance frequencies and bandwidths of the several variable resonators that make up these systems.

SOUND SPECIFICATIONS: DATA CARDS

In the description of sound for MUSE, resonators are grouped so that several of them can be excited by the same energy source. These groups are called Spectra. A specification of the states of the resonators in a Spectrum and the excitation function for those resonators at some point in time is called a Statement. Whenever "Spectrum" and "Statement" are used below in this technical sense, they will be capitalized.

Spectrum Specification

The experimenter describes the instantaneous frequency response of a particular Spectrum by supplying the resonance frequency and bandwidth in cycles per second of each resonance contributing to that Spectrum. More explicitly, the resonance frequency refers to the frequency of a pole in a

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passive electrical network which is analogous to the acoustical system to be simulated. The bandwidth of the resonance controls the real component or the attenuation of that particular pole. The value of a resonance bandwidth is the difference between the two frequencies at which the attenuation of the resonant network is 3 db greater than at the pole frequency under the assumption that the network has only this single resonance.

Excitation Source Specification

Supplying the states of resonances, as described above, can specify an acoustic resonating system at a fixed point in time. If enough points are picked, or if points of inflection are chosen and the program is designed to interpolate between them, a fairly complete description of the continuing response of say the human vocal tract, uttering speech can be made. To excite the resonant system, however, some provision must be made for an excitation source.

In the MUSE language, energy is supplied to the resonant system in the form of a train of shaped pulses. The pulses, whose response characteristics are fixed at the beginning of the run, can excite the system at periodic or pseudo-random intervals. The mode of excitation, buzz or noise, is specified in each Statement. The fundamental frequency of the buzz source and its amplitude are also specified. When the noise option is used, the repetition rate must also be supplied since the pulses are shaped in terms of decibels per octave above the fundamental frequency. The fundamental frequency is given in cycles per second. The amplitude multiplier is a two-digit number specifying the relative amplitude of the source pulse (it is not a logarithmic quantity).

Timing Specification

Having specified the Spectra and their excitations for single points in time, these points must be fixed at particular times by entering in each

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Statement the time in hundredths of a second since the beginning of the sound sample.

It has been mentioned above that sparse specification of the variation of a Spectrum through time would suffice if some kind of interpolation is assumed. The translation phase of the MUSE program assumes that all variables in a Statement (except specifications of time and mode of excitation) change linearly between Statements. The values of each variable in successive Statements and the time interval between these Statements determines the rate of this change. If a variable has the same value in successive Statements, that particular variable remains constant throughout the interval between those two Statements.

Sorting the Specification Cards

In the process of running the program, each Statement is read in as needed. Since interpolation between Statements is called for, it is necessary that as the calculations reach the "time" value of one Statement, the next Statement in each Spectrum must be read into the computer. The Spectra are independent of each other so ordering the Statements when specifying multiple Spectra can be fairly involved.

Although it is not necessary for running the system, it is recommended that a sorting field, not read by the computer, be included in the data cards. This sorting field contains in order a single-digit field that is zero ("0") for the first card in a Spectrum and a one ("1") for all other cards, the time value from the previous statement in the Spectrum, and the Spectrum number.

Data Card Formats

The format of the data cards whose fields have been described above are as given in Table I.

TABLE I

FORMAT OF A SOUND SPECIFICATION DATA CARD

Field or Variable Name	Column
Mode of excitation and card type identification: "0" = periodic excitation; "1" = noise excitation	1
Number of Spectra ("1" through "9")	2
Time (in the form XXXX. XX sec)	3-8
Amplitude Multiplier (XX arbitrary units)	9-10
Fundamental Frequency (XXXXX cps)	11-15

Resonance Specifications for Resonance Number i (i = 1, 2 ..., 8), where

bandwidth = b_i (XXX cps), frequency = f_i (XXXX cps):

b_1	16-18
f_1	19-22
b_2	23-25
f_2	26-29
b_3	30-32
f_3	33-36
b_4	37-39
f_4	40-43
b_5	44-46
f_5	47-50
b_6	51-53
f_6	54-57
b_7	58-60
f_7	61-64
b_8	65-67
f_8	68-71

Sorting Field

"0" for first card in Spectrum, "1" for all others	73
Time from Previous Card in this Spectrum	74-78
Spectrum Number	79

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Any resonances that are not used can be left blank.

At this time, a MUSE Statement is presented in its entirety on a single card. Possible future expansions of the input language to multiple cards justify the use of "Statement" as a special term.

CONTROL CARDS

There are three control cards that must be used in the operation of the MUSE program. These are not acoustic data but serve to set up parameters and options for the processing of the sound specifications.

Parameter Control Card

The first control card is identified by a "2" punched in Column 1. This card specifies for the entire set of data which follows it, the number of spectra, the number of resonances in each of these spectra, the response characteristics of the source function, the sampling period of the output waveform and a field controlling program options.

The number of spectra depends upon the number of independently excited resonant systems desired (for speech synthesis the question of number of Spectra is discussed under "Selection of Spectrum Parameters"). In the present version of the program, all spectra have the same number of resonances, hence, only one entry is necessary in the "2" control card. The response characteristics of the source functions in all Spectra are the same and are specified in terms of the slope of their frequency response in db per octave above the fundamental. The sampling period is usually fixed at 44×10^{-6} seconds, the program option field at "00."

The format of the first control card is as given in Table II.

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Table II

Format of MUSE Control Card, Type "2"

Field or Variable Name	Column
Identification Field (contains a "2")	1
Number of Spectra ("1" to "9")	2
Sampling Period (in secs x 10^{-6}, usually "000044"	3-7
Number of Resonances ("01 to "08")	8-9
Source Characteristic (in db per octave x 10^{-1}; for instance, "060" is 6db per octave)	10-12
Program Option (usually "00")	13-14

End Cards

There are two kinds of control cards which signal the end of a set of data. Any card with a "4" in Column 1 signals the program that there are no more Statements in this sound segment and that the run is over. A "5" in Column 1 indicates the end of this sound segment and, in addition, sets up the program to accept the specifications for another sound segment preceded by its initial control card. When either of these end cards is read, the program begins processing the computed samples for the conversion phase. About one second of silence is automatically included on the end of each sound segment to erase a section of the output digital tape. The silent interval prevents spurious bits immediately following the waveform samples on the output tape from ruining the synthesized sound segment during the conversion process.

SECTION IV

SPEECH SYNTHESIS WITH THE MUSE SYSTEM: AN EXAMPLE

INTRODUCTION

Although implicit in the description given in Section III, the process of
using MUSE for synthesizing sound is best clarified by presenting an example.
A complex example, the speech utterance "All's well that ends well," has been
chosen so that all features of MUSE can be demonstrated.

This example represents approximately 2 seconds of speech. It took
approximately 200 seconds of computer time to synthesize this example.

The first steps in the synthesis procedure are common to all so-called
"terminal analog" synthesizers.[2, 3, 4] First the utterance is recorded and
sound spectrograms are made.[5] Amplitude sections, displays of the
Spectrum of the speech during some selected short interval of time, can be
made to clear up ambiguous areas on the time-frequency-amplitude graph. An
additional useful datum is an oscillograph of the utterance with the time scale
such that the period of the fundamental and the over-all amplitude can be
measured throughout the utterance. These data for the sample "All's well that
ends well," from which an analysis of the utterance can be made, are presented
in Figure 2.

Selection of Spectrum Parameters

The next step in the analysis procedure is to decide how many Spectra
will be necessary to specify the sound sample to be synthesized. Perhaps the
most important factor in making this decision for synthesizing speech is a
heuristic one; i. e., how many Spectra will best fit the experimenter's view of
the speech process? For the example presented here, three spectra are used.
Each corresponds to a different mode of operation of the vocal apparatus. The

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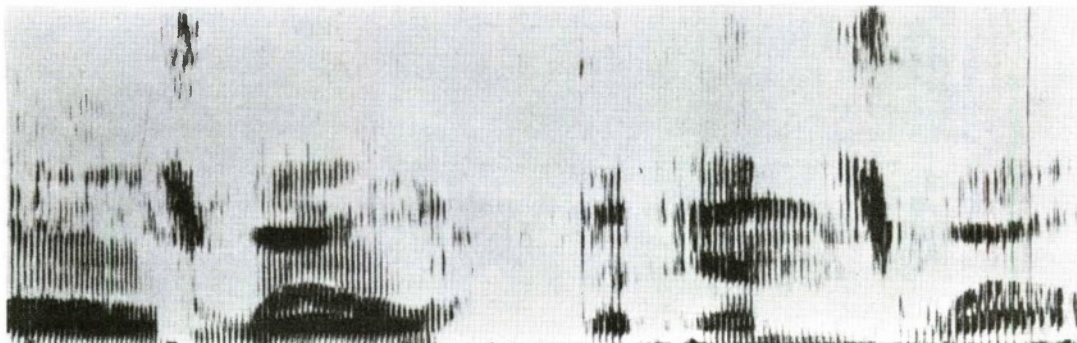
Figure 2a. Sonogram of the Utterance
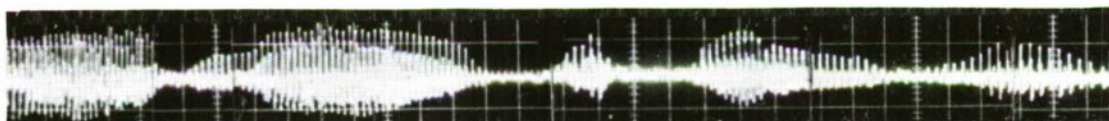
Figure 2b. Oscillogram of the Utterance

Figure 2. Spectrum of the Utterance, "All's well that ends well," Spoken by a Native American.

first spectrum corresponds to the mouth and throat excited by periodic laryngeal pulses. In other words, it is used for all voiced sounds. The second spectrum corresponds to any excitation of the vocal apparatus by noisy sources. Fricatives, aspirates, and some stops call for the use of this spectrum. The third Spectrum represents the contribution of the nasal cavities to nasalized vowels and consonants.

A similar division of the speech process into three more or less independent spectra is implied in the synthesizers built by Fant and K. N. Stevens.* A more concise description of speech utterances can be accomplished using only a single Spectrum with a corresponding degradation in the quality of the synthetic speech.

The other important decision to be made at this point in the analysis involves the number of resonances in the Spectra. Three resonances are a minimum number for intelligible speech. Higher frequency resonances contribute to the realism of the speech and may be important in realizing a particular speaker's voice. Since calculation of these extra resonances takes computer time, some restraint is to be exercised. In the present example, four resonances per Spectrum are specified. The resulting speech is highly intelligible but the speakers are generally not identifiable.

The slope of the power spectrum of the excitation source must be decided upon at this point also. Certain theoretical considerations by Fant[6] give 6 db per octave attenuation as a good empirical approximation to the over-all spectrum slope.

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*These synthesizers are discussed in References [3] and [4].

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The values chosen for the number of Spectra, the number of resonances per Spectrum, and the slope of the source spectrum are entered into the "2" type control card as specified under "Parameter Control Card," page 9.

SEGMENTATION

Since MUSE interpolates between parameter values on successive statements, it is necessary to select times for the Statements between which the Spectrum parameters change only linearly. This is done by close examination of the spectrograms and oscillograms of the speech utterance. The segmentation is entirely acoustic and has little to do with phonetic divisions. An easy way to place the Statements and find parameter values is to plot the resonance frequencies for each Spectrum as a function of time. Figure 3 contains these plots for the example being considered here. The resonance values can be left constant or can be changed linearly when the amplitude multiplier is zero. (For example, see times 0.00 to 0.06, 1.98 to 0.20 in Figure 3.)

It can be seen from Figure 3 that the Spectra are time-independent; that is, the time segments in difference Spectra do not necessarily coincide. The values of the various parameters can be read from these graphs at the points corresponding in time to the Statements. The parameter values are then entered into a coding form and punched onto IBM cards in the format described under "Data Card Formats," page 7. After sorting the cards on the sorting field, the specification data are only ready for calculation. A printout data for these cards is given in Table III for the sample utterance.
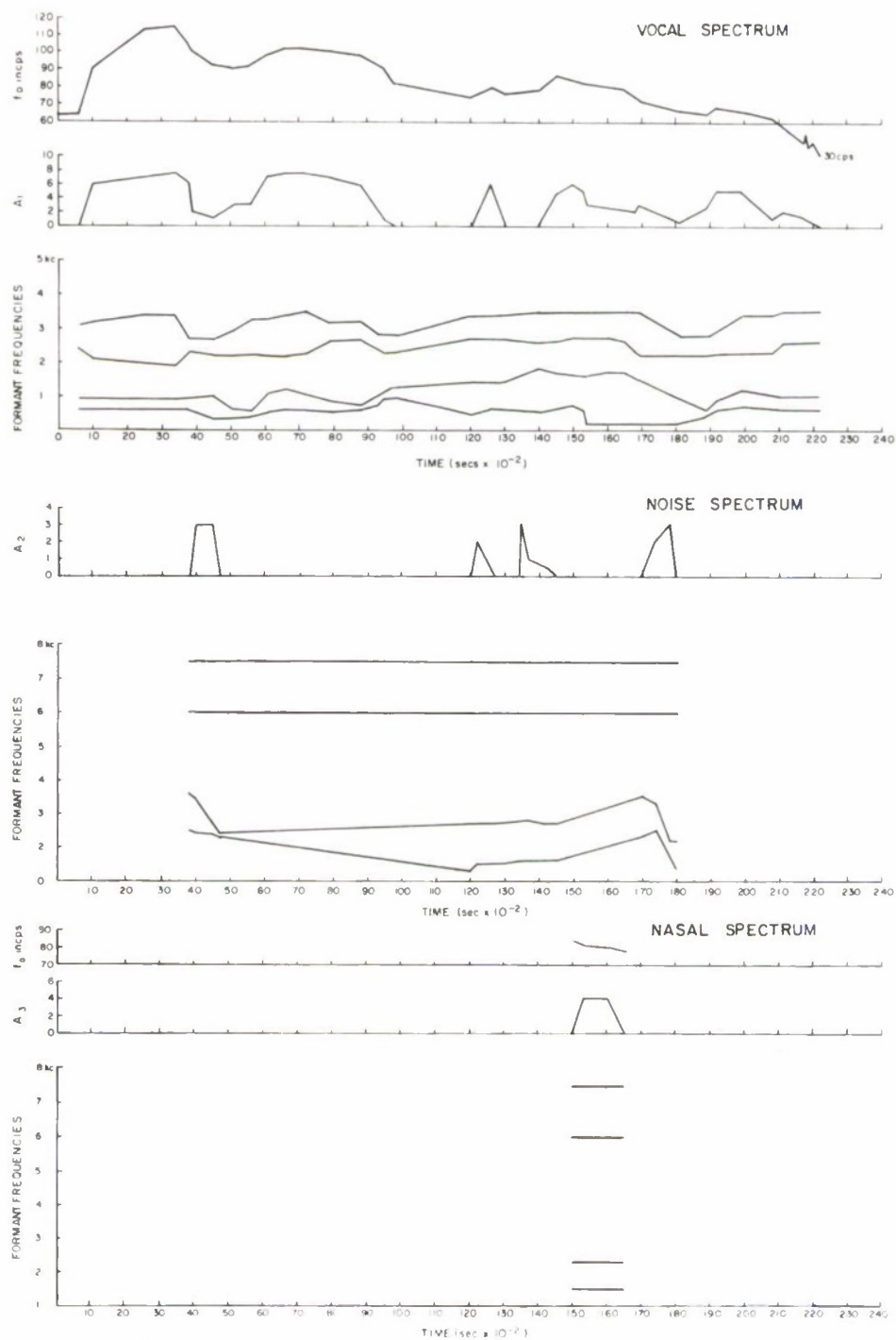
Figure 3. Tracings of the Sonograms (Figure 2a) from which the Input Data to MUSE are Copied. (The Vocal Spectrum Number is "1," the Noise Spectrum is "2," and the Nasal Spectrum is "3.")

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Table III

Input Data For The Utterance "All's Well That Ends Well"

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b_1	f_1	b_2	f_2	b_3	f_3	b_4	f_4
0	1	0	0	64	50	600	50	900	70	2400	120	3100
1	2	0	0	100	100	2500	60	3600	100	6000	100	7500
0	3	0	0	84	100	1500	90	2300	300	6000	400	7500
0	1	6	0	64	50	600	50	900	70	2400	120	3100
1	2	38	0	100	100	2500	60	3600	100	6000	100	7500
0	3	150	0	84	100	1500	90	2300	300	6000	400	7500
0	1	10	60	90	50	600	50	900	70	2100	120	3200
0	1	25	70	112	50	600	50	900	70	2000	120	3400
0	1	34	75	114	50	600	50	900	70	1900	120	3400
0	1	38	60	104	100	600	100	900	100	2300	200	2700
0	1	39	20	100	100	500	100	900	100	2300	200	2700
1	2	40	40	100	100	2400	60	3400	100	6000	100	7500
0	1	45	10	92	100	300	100	1000	100	2200	200	2700
1	2	45	40	100	100	2400	60	2700	100	6000	100	7500
0	1	51	30	90	70	300	80	600	100	2200	200	2900
1	2	47	0	100	60	2300	60	2400	100	6000	100	7500
1	2	120	0	100	80	1300	80	2700	150	6000	150	7500
0	1	56	30	92	60	400	70	500	100	2200	200	3300
0	1	61	70	98	40	500	50	1100	70	2200	100	3300
0	1	66	75	102	50	600	50	1200	70	2200	100	3400
0	1	72	75	102	50	600	50	1000	100	2300	150	3500
0	1	79	70	100	50	500	50	800	120	2600	200	3200
0	1	88	60	98	60	600	60	700	120	2700	120	3200
0	1	93	30	94	70	700	80	1000	100	2400	100	2800

Table III (cont'd)

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b_1	f_1	b_2	f_2	b_3	f_3	b_4	f_4
0	1	95	10	90	70	900	150	1100	100	2300	100	2800
0	1	98	0	82	100	900	150	1200	100	2300	100	2800
0	1	120	0	74	100	500	150	1400	150	2700	150	3400
0	1	126	60	80	50	600	70	1400	90	2700	100	3400
1	2	122	20	100	80	1500	80	2700	150	6000	150	7500
1	2	127	0	100	80	1500	80	2700	150	6000	150	7500
0	1	128	35	78	50	600	70	1400	90	2700	100	3400
1	2	134	0	100	80	1600	80	2800	150	6000	150	7500
0	1	130	0	76	50	600	70	1400	90	2700	100	3400
0	1	140	0	78	50	500	70	1800	90	2600	100	3500
1	2	135	40	100	80	1600	80	2800	150	6000	150	7500
1	2	137	10	100	80	1600	80	2800	150	6000	150	7500
1	2	141	30	100	80	1600	80	2700	150	6000	150	7500
0	1	145	45	86	50	600	50	1700	90	2600	100	3500
1	2	145	0	100	80	1600	80	2700	150	6000	150	7500
0	1	150	60	84	50	700	50	1600	90	2700	100	3500
1	2	170	0	100	60	2300	50	3500	100	6000	100	7500
0	1	153	50	82	60	500	60	1600	90	2700	100	3500
0	3	153	40	82	100	1500	90	2300	300	6000	400	7500
0	1	154	30	82	90	200	100	1600	120	2700	150	3500
0	3	160	40	80	100	1500	90	2300	300	6000	400	7500
0	1	160	25	80	90	200	100	1700	120	2700	150	3500
0	1	165	25	78	90	200	100	1700	120	2600	150	3500
0	3	165	0	78	100	1500	90	2300	300	6000	400	7500
0	1	168	20	74	90	200	100	1600	120	2300	150	3500
0	3	222	0	78	100	1500	90	2300	300	6000	400	7500

Table III (Concl'd)

ID	Spectrum Number	Time	Amplitude	Fundamental Frequency	b_1	f_1	b_2	f_2	b_3	f_3	b_4	f_4
0	1	169	30	72	90	200	100	1500	120	2200	150	3500
0	1	181	5	66	90	200	100	1000	120	2200	150	2800
1	2	174	40	100	50	2500	50	3300	100	6000	100	7500
1	2	178	50	100	50	1700	50	2200	100	6000	100	7500
1	2	180	0	100	50	1400	50	2200	100	6000	100	7500
1	2	222	0	100	50	1400	50	2200	100	6000	100	7500
0	1	189	25	64	90	400	100	600	120	2200	150	2800
0	1	192	50	68	50	600	50	900	90	2300	100	3000
0	1	199	50	66	50	700	50	1200	90	2300	100	3400
0	1	208	10	62	50	600	50	1000	90	2300	100	3400
0	1	211	20	56	50	600	50	1000	90	2600	100	3500
0	1	216	15	50	50	600	50	1000	90	2600	100	3500
0	1	222	0	30	50	600	50	1000	90	2600	100	3500

EVALUATION

The resulting synthetic speech is highly intelligible if somewhat artificial sounding. Recordings have been rather widely demonstrated, with almost total comprehension of the utterances reported by the audience. A spectrogram and oscillogram of the original and synthesized versions of the utterance "All's well that ends well" are given in Figure 4.
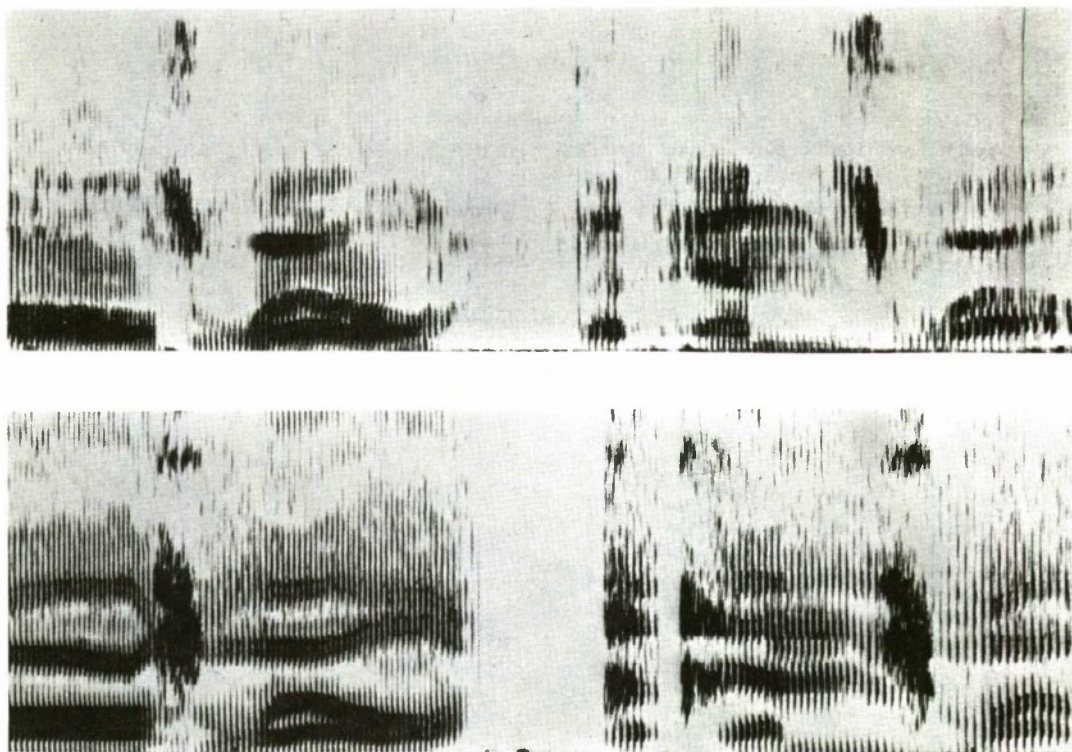
Figure 4a. Sonograms of the Original (Top) and Synthesized (Bottom) Versions of the Utterance
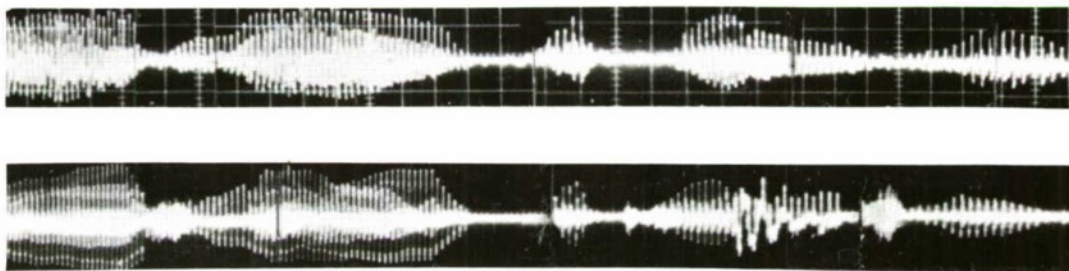
Figure 4b. Oscillograms of the Original (Top) and Synthesized (Bottom) Versions of the Utterance

Figure 4. Comparison of Sonograms and Oscillations of Original and Synthesized Utterance, "All's well that ends well."

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SECTION V

FLOW OF THE PROGRAM

INPUT PROCESSING

In order to avoid a "hardware" limitation on the number of data cards or number of spectra, the data cards are read into the computer as needed by an input subroutine. When a new card is read, spectrum parameters are set up and an interpolation increment for each Spectrum parameter is calculated. These increments are added after each period of the excitation pulse. Although "continuous" interpolation (i. e., after each waveform ordinate) would more closely approximate the smooth changes in the vocal tract, substantial savings in computation time accrue if the interpolation is lumped in coordination with the source periods.

CALCULATION PHASE

The two (momentarily) constant coefficients of the following second-order difference equation are the recipients of the interpolation increments:

$$x_t = Ax_{t-\Delta t} + Bx_{t-2\Delta t} + S ,$$

where

$$A = \left[2e^{-2\pi b_{ij}\Delta t} \cos(2\pi f_{ij}\Delta t) \right] ,$$

$$B = -\left[e^{-4\pi b_{ij}\Delta t} \right] ;$$

and where

$\quad b_{ij}$ = bandwidth of the ith resonance in the jth spectrum,

$\quad f_{ij}$ = frequency of that resonance,

$\quad \Delta t$ = sampling period,

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x_t = amplitude at time, t, and

S = relative amplitude of the source function.

Evaluation of this difference equation for successive sampling periods results in a series of ordinates of the waveform of a single resonance excited by a pulse of amplitude, S, once per period of the source function. At each sampling point, t, the ordinates of each resonance are summed, and these sums are added over all Spectra. The resulting over-all ordinate is

$$x_t = \sum_{j=1}^{\ell} \sum_{i=1}^{K} x_{ijt} \ ,$$

where

i = resonance index,

j = spectra index, and

ℓ and K = upper limits of the indices (the number of spectra and resonances given in the "2" control card).

As the calculation proceeds, the waveform ordinates are stored temporarily in blocks of 12,000 on a magnetic tape.

OUTPUT PROCESSING

When one of the final control cards (with either a "4" or "5" in Column 1) is encountered, the final output routine is begun. The blocks of waveform ordinates stored temporarily on tapes are read into the computer, scaled, packed and converted to a steady stream of six-bit numbers written as a single record in low density on the output tape. If the final control card is a "4," the program is finished and control is returned to the monitor system. If the "5"

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control card terminates the utterance, the program clears storage space and begins reading in the control and data cards for the next utterance.

SECTION VI

RUNNING THE PROGRAM AND CONVERTING THE OUTPUT DATA

INTRODUCTION

This section describes the preparation of the input deck for computation, the running of the program itself, and the operation of the digital-to-analog converter.

RUNNING THE PROGRAM

The data cards, after sorting on the field described under "Sorting the Specification Cards" on page 7, are preceded by the "2" control card, followed by the "4" or "5" control card and inserted behind the "*DATA" card following the MUSE program binary deck.

Tapes needed in running the program are B5 and B6 and A10. The B-channel tapes provide temporary storage while the final output is written on an A10. Under ordinary operation there are no stops in the program. Any on-line printouts are used by an observer only to keep track of the program's operation. They do not require action from the computer operators.

OUTPUT CONVERSION PROCESS

While the program's operation is quite routine, the output conversion process definitely is not (see Figure 1 for an over-all schematic of the conversion system). It is advisable to make the connections between the converter and the tape drive under the supervision of IBM customer engineers. Computer time is conserved if the tape drive containing the digital output tape is disconnected from the computer during a routine halt between two runs. An extra "terminator" for the detached tape drive must be attached to the converter. The bandpass filter on the output of the converter should be set at a nominal low-pass cutoff of about 10,000 cps.

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The tape recorder should be started before the tape drive. A switch on the converter supplies the signals necessary for starting the digital tape drive. The conversion process then continues in real time. When conversion is finished, the digital tape can be stored for later use and the tape drive can be re-attached to the computer.

DIGITAL-TO-ANALOG CONVERSION EQUIPMENT

The digital-to-analog converter that was used in the MUSE system is only one of several circuits that would serve as a conversion device.

An IBM cable attachment plug is part of the converter used. The input to the read amplifiers comes from this plug. The equipment is most conveniently mounted on an ordinary rack with space provided for the bandpass filter used to smooth the output of the converter.

REFERENCES

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3. Quarterly Progress and Status Report 2/1961, Speech Transmission Lab., Royal Institute of Technology, Stockholm, Sweden, 16.

4. George Rosen, "Dynamic Analog Speech Synthesizer," J. Acoust. Soc. Am., 30 (1958), 201-209.

5. Potter, Kopp, and Green, Visible Speech, New York, Van Nostrand, 1947.

6. C. Gunnar M. Fant, Acoustic Theory of Speech Production, The Hague, Mouton, 1960.

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Following is the FORTRAN program listing of the MUSE Program.[7]

```
      W.  SLAWSON    MUSE2, A SOUND SYNTHESIZER                          4/10/63
C
      ••••••••=••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
      COMMON   FREQ,FAND,SREQ,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,    MU200300
     XSMIS,CMIS,FCCA,FCCB,FORCE,PERIOD   ,IIN                            MU200400
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
     XGREAT, SAMPER
     X  , STOR
     X,CUTL
     X,PULSE,CPULSE,CP
     X,PERTY
     X, OPTION
      DIMENSION   FREQ(  8, 10), FAND( 8, 10), SREQ( 8, 10), SAND( 8,MU200500
     X 10), DCOA(  8, 10), DCOB( 8, 10), VAL( 2,  8, 10), TOT( 10),    MU200600
     X STORE( 100), PUTIN( 21) ,  FMIS( 4, 10) , SMIS( 4, 10 ),        MU200700
     XCMIS(2,10), FCCA(8,10), FCCB(8,10),  FORCE(8,10)      ,
     X PERIOD ( 10 )      ,   IIN(2)                                   MU200900
     X,STOR(12000)
     X,CUTL(2000)
     X,PULSE(8,10),CPULSE(8,10)
     X,PERTY(10)
      EQUIVALENCE ( STORE, STOR )
C
C
C     ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C     HOUSEKEEP AND READ CONTROL CARD.                                   MU201100
C     ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
 100  READ INPUT TAPE 5,10,IIN(1), ISPEC, SAMPER, IRESON, DB,  OPTION
 10   FORMAT  (2I1,F5.0,I2,F3.1 , F2.0          )
      IF ( OPTION - 2. ) 25,15,15
 15    PRINT  11
 11    FORMAT ( 1H1  )
       PRINT 12,IIN(1),ISPEC,SAMPER,IRESON, DB, OPTION
 12    FORMAT   (1H I2, I3, E15.7, I3,2E15.7)
 25    WRITE OUTPUT TAPE 6, 11
       WRITE OUTPUT TAPE 6, 12, IIN(1), ISPEC, SAMPER, IRESON, DB,OPTION
       SAMPER  =   SAMPER  •  10. ••(-6          )
       LCOUNT = 0                                                       MU201300
       SMALL  = C.                                                      MU201500
       GREAT=0.
       REWIND 8
       L      = 1                                                       MU201600
       ISW2   = 2                                                       MU201700
        NAR = 12000
        IF ( OPTION - 5. ) 45, 50, 60
 45     IF ( OPTION - 4. ) 60,57,60
 50     NAR = 999
        GOTO 60
 57     NAR=100
 60     DO  110  J=1,ISPEC
        DO 112  I=1,IRESON                                              MU202000
        VAL(1,I,J)  = 0.                                                MU202100
 112    VAL(2,I,J)  = 0.                                                MU202200
        PERTY(J)  =  0.
 110    TOT(J)      = 0.                                                MU202300
        DO 55 I=1,NAR
```

```
 55    STCR(I) = C.
       TIME          = 0.                                               MU202400
C
C      ................................................................
C                                             END OF HOUSEKEEPING. SET
C                                             UP INITIAL CONDITICNS.
C      ................................................................
C
 115      CC 130 J=I, ISPEC
          J-J
          CALL SUB2( IMS2 )
 130      CALL SUB3
          CC 147 J=1, ISPEC
          J=J
          CALL SUB2( IMS2 )
          CALL SUB4
 147      CALL SUB5
          IF (CPTICN )  15C, 150, 149
 149      PRINT 4C20
          WRITE CUTPUT TAPE 6, 4020
 4020     FCRMAT (   12H BEFCRE 15C.
          CALL  WCUMP
C
C      ................................................................
C      PEGIN MAIN FLCW                                                  MU202600
C      ................................................................
C
 150      J     = 1                                                     MU205300
 155      TCT(J)        0.C
 6C0      DC  620 I=1,IRESCN                                            MU219800
          TEMP   =   (FCCA(I,J)   *   VAL(1,I,J))  -   FCCB(I,J)        MU219900
      X*  VAL(2,I,J)  +  FCRCF(I,J)
          FCRCF(I,J) = C.C
          VAL(2,I,J)    =    VAL(1,I,J)                                 MU220200
          VAL(I,I,J)    =    TEMP                                       MU220300
 620      TCT(J)    =    TCT(J)     +    TEMP
 1553     IF(SMIS(1,J) - TIME) 163,163,1552
 1552     IF (PERTY(J) - TIME ) 160, 160, 157
 157      IF ( ISPEC - J )  159 , 159, 158
 158      J       = J+1                                                MU206100
          GC TC  155                                                   MU206200
C
 159      TEMP =    C.0
          CC 820   J=1,ISPEC                                            MU223900
 820      TEMP   =TCT(J)+   TEMP                                        MU224000
          STCR(L) =  TEMP
          TIME    = TIME + 1.                                          MU220500
          L = L+1
          IF   ( NAR - L  )       1591, 150 , 150
C
 1591 CALL  SUB7
 1595 L=1                                                              MU206800
          GC TC  150                                                   MU206900
C
C      ................................................................
C                                             PERIOD OF THE FUNDAMENTAL
```

```
C                                                   IS OVER.  INCREMENT PARAMFT-
C                                                   ERS AND START A NEW PERICD.
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
 160    DC  920     I=1, IRFSCN
        PULSE(I,J) =   PULSE(I,J) + OPULSE(I,J) + PERICO(J)
        FCCA(I,J)  =   FCCA(I,J) + DCCA( I,J )      •PERIOD(J)              MU226400
 920    FCCB(I,J)  =   FCCB(I,J) + DCCB( I,J )      •PERIOD(J)              MU226500
        FMIS(2,J)  =   FMIS(2,J) + OMIS(1,J)        •PERIOO(J)              MU226600
        FMIS(3,J)  =   FMIS(3,J) + CMIS(2,J)        •PERICD(J)              MU226700
 161    CALL SUB5                                                          MU207200
        GC TO 157                                                          MU207300
C
C
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C                                                   PROCESS A NEW CARD
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
 163    CALL SUB3                                                          MU207500
 164    CALL SUB2( IMS2 )                                                  MU207600
        IF ( IMS2 - 1 )  167, 166, 165                                     MU207700
 167    CALL SUB4                                                          MU208300
        GC TC 1552
C
C
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C                                                   ENO CARD HAS BEEN REACHEC.
C                                                   START FINAL PROCESSING.
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C.
 165    CC1653  IX = L,NAR
 1653   STCR (IX)  = 0.C
        CALL SUB7
        IF (OPTICN -4. ) 175,1651,1651
 175    CC 1751   IX = 1,NAR
 1751   STCR(IX)     = C.C
        LCCUNT = LCCUNT +    6
        CC  1752  IX=1,6
 1752   CALL RITE(STCR)
        REWINC 8
        REWINC 1C
        DC 185 IX = 1,LCCUNT
 180    CALL REEC(STCR)
 5002 FORMAT  ( 1H E19.7, 5E20.7 )                                         19M9290
 185    CALL SUB1C (SMALL,GREAT,NAR,STOR,OUTL)
        ENDFILC 1C
 190    CALL SUB11                                                         19M9290
 1651 PRINT 4016
        WRITE CUTPUT TAPE 6, 4016
 4016 FCRMAT (12H ENC CF JOB.     )
        CALL WCUMP
 1652 IF(IMS2-2) 192,192,191
 191     GCTO 100
 192     CALL EXIT
C
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C       ERRCR    RCLTINES
C       •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
```

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```
166  PRINT  4017
     WRITE OUTPUT TAPE 6, 4017
4017 FORMAT ( 41H DATA CARD OUT OF ORDER. STOP EXECUTION.     )
     CALL WDUMP
     CALL EXIT
     END(1,1,0,0,C,0,C,0,0,0,0,0,C,0)
```

```
      SUBROUTINE SUB2(IRRS2   )                                         MU208800
      COMMON  FREQ,FAND,SREG,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,   MU208900
     XSMIS,DMIS,FCCA,FCCB,FORCE,PERIOD    , IIN                         MU209000
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
     XGREAT, SAMPER
     X  , STOR
     X,CUTL
     X,PULSE,CPULSE,CB
     X,PERTY
     X, OPTION
      DIMENSION   FREQ( 8, 10), FAND( 8, 10), SREG( 8, 10), SAND( 8.MU209100
     X 10), DCOA(  8, 10), DCOB(  8, 10), VAL( 2,  8, 10), TOT( 10),    MU209200
     X STORE( 100), PUTIN( 21) ,   FMIS( 4, 10) , SMIS( 4, 10 ),        MU209300
     XDMIS(2,10), FCOA(8,10), FCOB(8,10),  FORCE(8,10)        ,
     X PERIOD ( 10 )     ,  IIN(2)                                      MU209500
     X.STOR(12000)
     X,CUTL(2000)
     X,PULSE(8,10),CPULSE(8,10)
     X,PERTY(10)
      EQUIVALENCE ( STORE, STOR )
  200 READ INPUT TAPE 5, 2000,  IIN(1), IIN(2),(PUTIN(M), M=1,19 )
      IF ( OPTION- 2. ) 260, 250, 250
  250 PRINT 2001, IIN(1), IIN(2), (PUTIN(M), M=1,19)
 2001 FORMAT (1HC2I2, F7., F4., F8., 8(F5.,F6.))
  260 WRITE OUTPUT TAPE 6, 2001, IIN(1), IIN(2), ( PUTIN(M), M=1,19)
  201 IF (  IIN(1) - 2 )  210, 202, 205                                 MU209700
  202 PRINT 2002
      WRITE OUTPUT TAPE 6,2002
 2002 FORMAT (24H MISPLACED CONTROL CARD.            )
      CALL WDUMP
      CALL EXIT
  205 IF ( IIN(1) -3  )  206, 207, 245
  206 CALL WDUMP
      CALL EXIT
  207 PRINT 2003
      WRITE OUTPUT TAPE 6, 2003
 2003 FORMAT (50H CHANGE IN NUMBER OF RESONANCES. TO BE PROGRAMMED.  )
      CALL WDUMP
      CALL EXIT
  245 IF(IIN(1)-4) 208,208,240
  208 IRRS2 = 2                                                         MU210400
  209 RETURN
C     END CARD.                                                         MU210600
  210 IF (  IIN(2)  - J ) 215, 220, 215                                 MU210700
  215 IRRS2 = 1                                                         MU210800
      PRINT 4003
      WRITE OUTPUT TAPE 6, 4003
 4003 FORMAT ( 48H DATA CARDS FROM WRONG SPECTRUM. STOP EXECUTION.)
      CALL WDUMP
      CALL DUMP
  220 SMIS(2,J)  =  PUTIN(2)
  225 SMIS(3, J)  = 1. / ( PUTIN(3) * SAMPER  )
      SMIS(1,J) = PUTIN(1) / (100. * SAMPER)
      SMIS(4,J)      =    IIN(1)                                        MU211400
      M=4                                                               MU211500
```

```
         SUB2, READ DATA CARD INTO  S(J) REGIONS.                         4/10/63

      N=5                                                          MU211600
      TWOPI  =  2.   *   3.14150265
      DO 230  I=I, IRESON                                          MU211700
      SREG(I,J)    =  PUTIN( N  )          *  TWOPI               MU211900
      SAND(I,J)    =  PUT(N( M )           *TWOPI                 MU211800
      N=N+2                                                        MU212000
  230 M=M+2                                                        MU212100
      IRRS2  = 0                                                   MU212200
      GOTO 204
C     NORMAL RETURN.                                               MU212400
  240 IRRS2= 3
      GOTO 204
 2000 FORMAT  (  2  I1   , F5.0 , F2.0 , F6.0,  8( F3.0,F4.0 )  )  MU212500
      END(),1,0,0,C,0,0,0,0,0,0,C,C,0,0)



         SUB3, MOVE S(J) TO F(J) REGIONS.                         4/10/63

      SUBROUTINE  SUB3                                            MU212900
      COMMON  FREG,FAND,SREG,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS, MU213000
     XSMIS,DMIS,FCCA,FCCB,FORCE,PERIOD  ,IIN                     MU213100
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
     XGREAT, SAMPER
     X  , STOR
     X,OLTL
     X,PULSE,DPULSE,DH
     X,PERTY
     X, OPTION
      DIMENSION   FREQ( 8, 10), FAND( 8, 10), SREG( 8, 10), SAND( 8,MU213200
     X 10), DCOA( 8, 10), DCOB( 8, 10), VAL( 2, 8, 10), TOT( 10),  MU213300
     X STORE( 100), PUTIN( 21)  , FMIS( 4, 10) , SMIS( 4, 10 ),   MU213400
     XDMIS(2,10), FCOA(8,10), FCOB(8,10),  FORCE(8,10)      ,
     X PERIOD ( 10 )    ,  IIN(2)                                MU200900
     X,STOR(12000)
     X,OLTL(2000)
     X.PULSE(8,10),DPULSE(8,10)
     X,PERTY(10)
      EQUIVALENCE ( STORE, STOR )
  300 ISW =1                                                      MU213700
      DO 310 M=1,4
  310 FMIS( M,J )  =  SMIS( M, J )                                MU213900
      DO 320  I=1, IRESON                                         MU214000
      FAND( I,J )  =  SAND( I, J )                                MU214100
  320 FREG( I,J )  =  SREG( I, J )                                MU214200
      RETURN                                                      MU214300
      END(1,1,0,0,C,0,C,0,0,0,0,0,0,0,0)
```

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SUB 4   COMPUTE COEFFICIENT INCREMENTS

```
      SUBROUTINE SUB4
C     MY END IS MY BEGINNING.  FIDDLE WITH THE MIDDLE COEFFICIENTS.     MU214700
      COMMON  FREQ,FANO,SREQ,SANO,CCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,   MU214900
     XSMIS,DMIS,FCCA,FCOB,FORCE,PERIOO ,IIN                             MU215000
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
     XGREAT, SAMPER
     X  , STOR
     X,OLTL
     X,PULSE,CPULSE,DB
     X,PERTY
     X, OPTICN
      DIMENSION    FREQ(  8, 10), FANO(  8, 10), SREQ(  8, 10), SANO(  8,MU215100
     X 10), CCOA(  8, 1C), CCOB(  8, 10), VAL( 2,  8, 10), TCT( 10),    MU215200
     X STORE( 100), PUTIN( 21) ,  FMIS( 4, 10) , SMIS( 4, 10 ),         MU215300
     XDMIS(2,10), FCCA(8,10), FCOB(8,10),  FORCE(8,10)      ,
     X PERICC ( 1C )    ,  IIN(2)
     X,STOR(12000)
     X,OLTL(2000)
     X,PULSE(8,10),CPULSE(8,10)
     X,PERTY(10)
      EQUIVALENCE ( STORE, STOR )
  400 DTIME     =    SMIS(1,J)  -  FMIS(1,J)                            MU215600
      E = 2.7182818
      DO 410   I=1,IRESON                                              MU215700
      PULSE(I,J) =                 FMIS(2,J) *  SINF(  FREQ(1,J) * SAMPER )
     X *(( FREQ(I,J) * ( FMIS(3,J) * SAMPER ) / 6.2831053)) ** (-DB *
     X  .166096  )
      CPULSE(I,J)= (  (            SMIS(2,J) *  SINF( SREQ(1,J) * SAMPER )
     X *(( SREQ(I,J) * ( SMIS(3,J) * SAMPER ) / 6.2831853)) ** (-DB *
     X  .166096 ) ) - PULSE(I,J) ) / DTIME
      FCCA(I,J)    = (2.0 * E ** (-FANO(I,J) * SAMPER))    *COSF ( FREQ MU215800
     X(I,J) *       SAMPER )                                           MU215900
      DCCA(I,J)    =((2.0 * E **(-SANO  (1,J) *  SAMPER)  * COSF (SREQ MU216000
     X(I,J) *       SAMPER)) - FCOA(I,J)) / DTIME                      MU216100
      FCOB(I,J)    =    E ** (-2.0 * FANO (I,J)   * SAMPER)            MU216200
  410 CCCB(I,J)    = ( E ** (-2.0 * SANO(I,J) * SAMPER) - FCOB(I,J))   MU216300
     X / DTIME                                                         MU216400
      DO 420   I=1,2                                                   MU216500
  420 UMIS(1,J)    = (SMIS(I+1,J) - FMIS (I+1 , J) ) / DTIME           MU216600
      RETURN                                                           MU216700
      END(1,1,0,0,C,0,C,0,0,0,0,0,C,0,0)
```

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```
      SUBROUTINE SUB5
       COMMON  FREC,FANC,SREG,SAND,DCOA,CCOB,VAL,TOT,STORE,PUTIN,FMIS,    MU217200
      XSMIS,CMIS,FCCA,FCCB,FORCE,PERIOC ,IIN                             MU217300
      X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
      XGREAT, SAMPER
      X  , STCR
      X,CLTL
      X,PULSE,CPULSE,CB
      X,PERTY
      X, CPTICN
       CIMENSICN   FREC( 8, 10), FANC( 8, 10), SREG( 8, 10), SAND( 8,MU217400
      X 10), CCOA( 8, 1C), CCOB( 8, 10), VAL( 2, 8, 10), TCT( 10),     MU217500
      X STCRE( 1CO), PUTIN( 21) ,  FMIS( 4, 10) , SMIS( 4, 10 ),        MU217600
      XCMIS(2,10), FCOA(8,10), FCOB(8,10),  FORCE(8,10)        ,
      X PERICC ( 1C )     ,  IIN(2)
      X,STCR(1200C)
      X,CLTL(20CO)
      X,PULSE(8,10),CPULSE(8,10)
      X,PERTY(10)
       ECUIVALENCE ( STCRE, STOR )
       IF ( FMIS(4,J) - 1.)  500, 51C, 500                              MU217900
500    PERICC(J) =  FMIS(3,J)
       GC TO  520                                                       MU218100
510    CFWRAN = RCUN(CUMMY)
       CEWRAN=  (CEWRAN*(1./(1C00.*SAMPER)))+(1./( 5U0U.*SAMPER))
517    PERICC(J) = CEWRAN
520     PERTY(J)  =  PERTY(J) + PERICC(J)
       CC 530 I=1, IRESCN
530    FCRCE(I,J) = PULSE(I,J)
       RETURN                                                           MU218500
       ENC(1,1,0,0,C,0,C,0,0,0,0,0,0,C,0)
```

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```
      SUBROUTINE SUB7
      COMMON  FREC,FANC,SREQ,SAND,CCOA,CCOB,VAL,TOT,STORE,PUTIN,FMIS,    MU221100
     XSMIS,DMIS,FCCA,FCOB,FORCE,PERIOD ,IIN                             MU221200
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRFSON, L, IMS2, NAR,
     XCREAT, SAMPER
     X   , STOR
     X,CLTL
     X,PULSE,CPULSE,CB
     X,PERTY
     X, OPTION
      DIMENSION   FREQ(  8, 10), FANC(  8, 10), SREQ(  8, 10), SAND(  8,MU221300
     X 10), CCOA(  8, 10), CCOB(  8, 10), VAL( 2,  8, 10), TOT( 10),    MU221400
     X STORE( 100), PUTIN( 21) ,  FMIS( 4, 10) , SMIS( 4, 10 ),         MU221500
     XDMIS(2,10), FCOA(8,10), FCOB(8,10),  FORCE(8,10)      ,
     X PERIOD ( 10 )     ,  IIN(2)
     X,STOR(1200C)
     X,ISTOR(12CCC)
     X,CUTL(2000)
     X,PULSE(8,10),CPULSE(8,10)
     X,PERTY(10)
      EQUIVALENCE ( STORE, STOR )
     X,(STOR,ISTOR)
700   LCOUNT   = LCOUNT + 1                                            MU221800
      IF ( OPTION  - 4. ) 705, 707, 707
705   CALL RITE(STOR)
      GOTO 725
707   IF ( OPTION - 6. ) 720, 710, 720
710   PRINT  5001
      PRINT  5002,  STORE
720   WRITE  OUTPUT TAPE 6,   5001
5001  FORMAT ( 36H NAREA CONSECUTIVE WORDS OF OUTPUT.   )
      WRITE OUTPUT TAPE 6,  5002 ,  STORE
5002  FORMAT ( 1H E19.7,   5E20.7    )
725   DO  730   L=1,  NAR
      IF ( GREAT -STOR(L) )  740,  750,  750
740   GREAT  = STOR(L)
      GO TO  730                                                       MU222300
750   IF( SMALL  - STOR(L) ) 730,  730,  760
760   SMALL  = STOR(L)
730   CONTINUE                                                         MU222600
770   IF(SENSE SWITCH 5 ) 775,790
775   DIFF = GREAT - SMALL
      DO 780  L=1,NAR
780   ISTOR(L) = ((( STOR(L) - SMALL ) / DIFF ) * 512.) + 256.
      PRINT 7001
7001  FORMAT(120H  THERE IS A REPEATING DISPLAY ON THE CRT. TO STOP IT,
     XPUT SWITCH 5 UP. AFTER HALT, SW5 UP TO STOP TV, DOWN TO SEE MORE.)
790   RETURN
      END(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0)
```

```
      SUBROUTINE WDUMP
      COMMON  FREC,FAND,SREO,SAND,DCOA,DCOB,VAL,TOT,STORE,PUTIN,FMIS,
     XSMIS,DMIS,FCCA,FCCB,FORCE,PERIOD ,IIN
     X, ISW2, J, SMALL, ISPEC, LCOUNT, TIME,IRESON, L, IMS2, NAR,
     XGREAT, SAMPER
     X , STOR
     X,CLTL
     X,PULSE,CPULSE,DB
     X,PERTY
     X, OPTION
      DIMENSION   FREC( 8, 10), FAND( 8, 10), SREO( 8, 10), SAND( 8,
     X 10), DCOA(  8, 10), DCOB( 8, IO), VAL( 2,  8, 10), TOT( 10),
     X STORE( 100), PUTIN( 21) ,  FMIS( 4, 10) , SMIS( 4, 10 ),
     XDMIS(2,10), FCCA(8,10), FCOB(8,10),  FORCE(8,10)         ,
     X PERIOD ( 10 )    ,   IIN(2)
     X,STOR(1200C)
     X,CLTL(2000)
     X,PULSE(8,10),CPULSE(8,10)
     X,PERTY(10)
       EQUIVALENCE ( STORE, STOR )
       WRITE OUTPUT TAPE 6, 3001
 3001 FORMAT (119H                        J                  L
     X  OPTION           ISPEC           LCOUNT           IRESON)
       WRITE OUTPUT TAPE 6, 3002, ( J,L,OPTION, ISPEC,LCOUNT,IRESON )
 3002 FORMAT(1H I19, I20, F19.7, 3I20  )
       WRITE OUTPUT TAPE 6,3021
 3021 FORMAT (119H                       IMS2                  NAR
     X  TIME              SMALL                  GREAT            DB    )
       WRITE OUTPUT TAPE 6,3022, (IMS2, NAR, TIME, SMALL, GREAT,DB    )
 3022 FORMAT (1H I19,I20,4E20.7 )
       WRITE OUTPUT  TAPE 6, 3025
 3025 FORMAT  (11H IIN(X,J)            )
       WRITE OUTPUT TAPE 6, 3026,  IIN
 3026 FORMAT ( 1H I19, I20  )
       WRITE OUTPUT TAPE 6, 3013
 3013 FORMAT  (11H PUTIN(X)     )
       WRITE OUTPUT TAPE 6, 3004,   PUTIN
 3004 FORMAT  ( 1H F19.7,5E20.7  )
       WRITE OUTPUT TAPE 6, 3003
 3003 FORMAT  (11H FREC(I,J)    )
       WRITE OUTPUT TAPE 6, 3004, FREC
       WRITE OUTPUT TAPE 6, 3005
 3005 FORMAT  (11H FAND(I,J)    )
       WRITE OUTPUT TAPE 6, 3004, FAND
       WRITE OUTPUT TAPE 6, 3006
 3006 FORMAT  (11H SREO(I,J)    )
       WRITE OUTPUT TAPE 6, 3004, SREO
       WRITE OUTPUT TAPE 6, 3007
 3007 FORMAT  (11H SAND(I,J)    )
       WRITE OUTPUT TAPE 6, 3004,  SAND
       WRITE OUTPUT TAPE 6, 3014
 3014 FORMAT  (11H FMIS(I,J)    )
       WRITE OUTPUT TAPE 6, 3004,  FMIS
       WRITE OUTPUT TAPE 6, 3015
 3015 FORMAT  (11H SMIS(I,J)    )
       WRITE OUTPUT TAPE 6, 3004,  SMIS
```

```
      WRITE OUTPUT TAPE 6, 3016
 3016 FORMAT  (11H CMIS(I,J)    )
      WRITE OUTPUT TAPE 6, 3004,     DMIS
      WRITE OUTPUT TAPE 6, 3017
 3017 FORMAT  (11H FCCA(I,J)    )
      WRITE OUTPUT TAPE 6, 3004,     FCOA
      WRITE OUTPUT TAPE 6, 3018
 3018 FORMAT  (11H FCCB(I,J)    )
      WRITE OUTPUT TAPE 6, 3004,     FCOB
      WRITE OUTPUT TAPE 6, 3008
 3008 FORMAT  (11H CCCA(I,J)    )
      WRITE OUTPUT TAPE 6, 3004,     DCOA
      WRITE OUTPUT TAPE 6, 3009
 3009 FORMAT  (11H CCCB(I,J)    )
      WRITE OUTPUT TAPE 6, 3004,     DCOB
      WRITE OUTPUT TAPE 6, 3010
 3010 FORMAT  (11H VAL(X,I,J)   )
      WRITE OUTPUT TAPE 6, 3004,     VAL
      WRITE OUTPUT TAPE 6, 3011
 3011 FORMAT  (11H TOT(J)       )
      WRITE OUTPUT TAPE 6, 3004,     TOT
      WRITE OUTPUT TAPE 6, 3012
 3012 FORMAT  (11H STORE(L)     )
      WRITE OUTPUT TAPE 6, 3004,     STORE
      WRITE OUTPUT TAPE 6, 3019
 3019 FORMAT  (11H FORCE(I,J)           )
      WRITE OUTPUT TAPE 6, 3004,     FORCE
      WRITE OUTPUT TAPE 6, 3020
 3020 FORMAT  (11H PERICD(J)    )
      WRITE OUTPUT TAPE 6, 3004,     PERIOD
      WRITE OUTPUT TAPE 6, 3023
 3023 FORMAT (15H CPULSE(I,J)              )
      WRITE OUTPUT TAPE 6, 3004,     DPULSE
      WRITE OUTPUT TAPE 6, 3024
 3024 FORMAT (15H   PULSE(I,J)             )
      WRITE OUTPUT TAPE 6, 3004,     PULSE
      WRITE OUTPUT TAPE 6, 3027
 3027 FORMAT ( 15H  PERTY(J)
      WRITE OUTPUT TAPE 6, 3004, PERTY
      RETURN
      END(1,0,0,0,C,0,0,0,0,0,0,0,0,0,0)
```

37

SUBROUTINE 1C   SCALING AND PACKING ROUTINE

SCALING AND PACKING SUBROUTINE
CCCO2   ENTRY   SUB10

LINKAGE CIRECTCR
CCC00   CCCO0CCOCCCO
00001   62642201CC6C

```
00002   0634 00 4 CCC6C   SUB10   SXA     XSAVE,4
CC003   0634 CO 2 CCC61           SXA     XSAVE+1,2
C0004   0634 CO 1 CCC62           SXA     XSAVE+2,1
C0005   0500 60 4 CCCO3           CLA*    3,4
0CCC6   C601 CO 0 CCC77           STO     NAR
CCC07   0500 60 4 CCCO2           CLA*    2,4
00010   0601 CO 0 0CC66           STO     GREAT
00011   0500 60 4 CCC01           CLA*    1,4
00012   0601 00 0 CCC65           STO     SMALL
C0013   0500 00 4 CCC04           CLA     4,4           LOCATION OF STOR
00014   0734 CO 1 CCC0C           PAX     ,1
00015   I 00001 1 CCC16           TXI     *+1,1,1
00016   0634 00 1 CCC37           SXA     L21,1
C0017   U500 CO 4 CCCC5           CLA     5,4           LOCATION OF OUTL
00020   0734 00 1 CCC00           PAX     ,1
00021   1 00001 1 CCC22           TXI     *+1,1,1
00022   0634 00 1 CCC47           SXA     L23,1
00023   0634 CO 1 CCC27           SXA     L24,1
00024   1 74C60 1 CCC25           TXI     *+1,1,-2000
0CC25   0634 00 1 CCC64           SXA     IO1,1
00026   0774 CO 2 C3720           AXT     2000,2
00027   0600 00 2 5C121   L24     STZ     OUTL,2
00030   2 00001 2 0C027           TIX     *-1,2,1
00031   0500 00 0 CCC66           CLA     GREAT         COMPUTE DIFF
00032   0302 00 0 CCC65           FSB     SMALL
0CC33   0601 00 C CCC67           STO     DIFF
                            *                            END OF HOUSEKEEPING
00034   0774 CO 1 CCC01           AXT     1,1
00035   0774 00 2 C3720           AXT     2000,2
C0036   0774 00 4 CCC06   L22     AXT     6,4
00037   0500 00 1 77462   L21     CLA     NARFA+1,1     SCALE AND PACK THIS RECORD
00040   0302 00 0 CCC65           FSB     SMALL
00041   0241 00 0 CCC67           FCP     DIFF
00042   0260 00 0 CCC72           FMP     SEVSIX
00043  -0300 00 0 CCC75           UFA     MAGIC
C0044   0760 00 C CCC11           FRN
00045  -0320 00 C CC074           ANA     MASK1
C0046   0767 00 4 CCC44           ALS     36,4
00047  -0602 00 2 5C121   L23     ORS     OUTL,2
00050   1 00001 I CCC51           TXI     *+1,1,1
00051   1 00006 4 CCC52           TXI     *+1,4,6
00052  -3 00044 4 CCC37           TXL     L21,4,36
00053   2 00C01 2 CC036           TIX     L22,2,1
00054  +0776C0002225             OCT     077600002225   SDH  OUTTAP
00055   0766 00 0 C2225           WTBB    OUTTAP
00056  -0540 00 0 CCC64           RCHB    IO1
00057   ^061 C0 0 C0057           TCOB    *
00060   0774 00 4 CCC0C   XSAVE   AXT     **,4
00061   0774 00 2 CCC00           AXT     **,2
```

SUBROUTINE 10   SCALING AND PACKING ROUTINE

```
00062    0774 00 1 CCCOC              AXT     **,1
00063    0020 00 4 CCC06              TRA     6,4
00064   -1 03720 0 44202    IO1       IOCT    OUTL-1999,,2000
00065    0 00000 0 CCOOO    SMALL     PZE
00066    0 00000 0 CCCCO    GREAT     PZE
00067    0 00000 0 CCCCO    CIFF      PZE
00070   +0C00CC0CCCC6        SIX      DEC     6
00071    0 00000 0 C0000    LOSIX     PZE
00072   +2067700CCCCC       SEVSIX    DEC     63.0
00073   +1764CCCCCCCO       PFIVE     OCT     1764000C0C00
00074   +C000CC000077       MASK1     OCT     77
00075   +233000000000       MAGIC     OCT     233000000000
00076   +000001000CCC       ONFDEC    OCT     1000000
00077    0 00C00 0 CCCCO    NAR       PZE
                    CCC05    OUTTAP    EQU     5
                    77461    NAREA     EQU     32561
                    5C121    OUTL      EQU     20561
                             END
```

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SUBROUTINE 11   WRITE A LONG RECORD

                 C3722   ENTRY   SUB11
                                         SUBROUTINE TO WRITE A LONG RECORD

    LINKAGE DIRECTOR
00000   OC000C0CCCCC
00001   S2642201C16C

                 CCC05   OUTTAP   EQU   5
                 CCC05   FTAPE   EQU   5
C0002   AREA   BSS   2000
                 C3720   L   EQU   2C00
03722   0634 00 2 C3751 SUB11   SXA   EXIT,2
03723   0772 C0 0 C2205   REWB   OUTTAP
03724 +0776CC002225   OCT   077600002225   SDHB   OUTTAP
03725 -0030 C0 0 C3726   TEFB   *+1
03726   0762 C0 0 C2225   RTBB   OUTTAP
03727 -0540 00 0 C3757   RCHB   IO9
03730   C061 00 0 C3730   TCOB   *
03731 -0022 CO 0 C3732   TRCB   *+1
03732 +0776CC001205   OCT   077600001205   SDLA   FTAPE
03733   0766 00 0 C1225   WTBA   FTAPE
03734   0540 C0 0 C3757   RCHA   IO9
03735   0640 00 0 C3756 DELAY   SCHA   T
03736   0534 C0 2 C3756   LXA   T,2
03737 -3 02736 2 C3735   TXL   *-2,2,AREA+L-N
03740   0762 00 0 C2225   RTBB   OUTTAP
03741 -0540 C0 0 C3757   RCHB   IO9
03742 -0061 C0 0 C3750   TCNB   END
03743 -0640 00 0 C3755   SCHB   S
03744   0534 C0 2 C3755   LXA   S,2
03745 -3 00004 2 C3742   TXL   *-3,2,AREA+2
03746   0544 00 0 C3757   LCHA   IO9
03747   OC20 00 C C3735   TRA   DELAY
03750   C060 00 0 C3750 END   TCOA   *
03751   0774 00 2 CCCC0 EXIT   AXT   **,2
03752 -0030 C0 0 C3753   TEFB   *+1
03753   0020 00 4 CCC01   TRA   1,4
03754   0000 00 C CCC01 ERROR   HTR   1
03755   0 00000 C CCCC0 S   PZE
03756   0 COC00 0 CCC0C T   PZE
                 CC764   N   EQU   500
03757 -1 03720 0 CCC02 IO9   IOCT   AREA,,L
                                  END

```
                    CCUNT    25

                         CCC02           ENTRY   REED

       LINKAGE DIRECTCR
  C0000   CC00000CCCC0
  C0001   512525246C6C

  0C002   0634 00 2 CCC12   REEC    SXA     EXIT,2
  C00C3   0500 00 4 CCC01           CLA     1,4
  0C004   0734 C0 2 CCC00           PAX     ,2
  CC005   1 50441 2 CCC06           TXI     *+1,2,-11999
  00006   0634 00 2 CCC14           SXA     IO,2
  00007   0762 00 0 C2221           RTBB    1
  00010  -0540 00 0 CCC14           RCHB    IO
  0C011   C061 00 C CCC11           TCOB    *
  0C012   0774 00 2 CCCC0   EXIT    AXT     **,2
  00013   0020 00 4 CCC02           TRA     2,4
  00014  -1 27340 0 CCCC0   IO      IOCT    **,,12000
                                    END




              SUBROUTINE FCR WRITING A5  RITE(STOR)

                              *         COUNT   25
                         CCC02          ENTRY   RITE

       LINKAGE DIRECTCR
  00000   CC0C0C00CCCC0
  00001   513163256C6C

  CC002   0634 C0 2 CCC12   RITE    SXA     EXIT,2
  00003   0500 00 4 CCC01           CLA     1,4
  0C004   0734 00 2 CCC00           PAX     ,2
  00005   1 50441 2 CCC06           TXI     *+1,2,-11999
  0C006   0634 C0 2 CCC14           SXA     IO,2
  00007   0766 00 0 C2221           WTBB    1
  00010  -0540 C0 0 CCC14           RCHB    IO
  00011   CC61 CC 0 CCC11           TCOB    *
  00012   0774 C0 2 CCC00   EXIT    AXT     **,2
  00013   0C20 00 4 CCC02           TRA     2,4
  00014  -1 27340 0 CCC0C   IO      ICCT    **,,12000
                                    END
```

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```
                        00021          ENTRY   RONN
                        00002          ENTRY   ROUN

        LINKAGE DIRECTOR
00000   00000000000000
00001   512445456000

00002   0560 00 0 00016   RDUN   LDQ RDUN+12,0
00003   0200 00 0 00017          MPY RDUN+13,0
00004   0763 00 0 00004          LLS 4,0
00005   0767 00 0 00004          ALS 4,0
00006   0765 00 0 00004          LRS 4,0
00007  -0600 00 0 00016          STQ RDUN+12,0
00010   0400 00 0 00016          ADD RDUN+12,0
00011   0601 00 0 00016          STO RDUN+12,0
00012   0771 00 0 00004          ARS 4,0
00013  -0501 00 0 00020          ORA RDUN+14,0
00014   0300 00 0 00020          FAD RDUN+14,0
00015   0020 00 4 00002          TRA 2,4
00016  +002312421637             OCT 2312421637,1737,200000000000
00017  +000000001737
00020  +200000000000
00021  -0634 00 1 00051   RONN   SXD IR1,1
00022  -0634 00 4 00052          SXD IR4,4
00023   0534 00 1 00044          LXA L20,1
00024   0500 00 0 00020          CLA RDUN+14,0
00025   0601 00 0 00053          STO C,0
00026   0074 00 4 00002          TSX RDUN,4
00027   0761 00 0 00000          NOP
00030   0300 00 0 00053          FAD C,0
00031   0601 00 0 00053          STO C,0
00032   2 00001 1 00026          TIX RONN+5,1,1
00033   0241 00 0 00045          FDP L20+1,0
00034   0500 00 0 00050          CLA L20+4,0
00035   0763 00 0 00043          LLS 35,0
00036   0302 00 0 00046          FSB L20+2,0
00037   0765 00 0 00043          LRS 35,0
00040   0260 00 0 00047          FMP L20+3,0
00041  -0534 00 1 00051          LXD IR1,1
00042  -0534 00 4 00052          LXD IR4,4
00043   0020 00 4 00002          TRA 2,4
00044   0000 00 0 00024   L20    HTR 20,0
00045  +205500000000             DEC 20.,.5,15.49193340,0
00046  +200400000000
00047  +204757573654
00050  +000000000000
00051   0000 00 0 00000   IR1    HTR 0,0
00052   0000 00 0 00000   IR4    HTR 0,0
00053   0000 00 0 00000   C      HTR 0,0
                                 END
```

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13. ABSTRACT

The MUSE system, an IBM 7090 computer program and associated conversion equipment, has been designed for use as a sound synthesizer. Concise descriptions of complex sounds including human speech are converted by the MUSE system into sound pressure waveforms. The inputs to the MUSE system are specifications of the changing resonance frequencies of multiple acoustic filter networks and of the changing frequencies and amplitudes of the sources of acoustic energy that excite those networks. The output of the MUSE system is a sampled waveform calculated for each resonance by the solution of a second-order difference equation. The results are summed over a single system of resonances and then the resonance systems are also added together. The resulting string of sampled waveform ordinates is written in digital form on magnetic tape. Conversion to a voltage waveform is accomplished by use of the standard IBM 729 IV tape transport unit and a simple digital-to-analog converter. Although the quality of the sound is somewhat degraded by tape wow and flutter, acceptable and highly intelligible speech has been synthesized.

DD FORM 1 JAN 64 **1473**

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Programming (Computers)						
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